Journal of Sustainable Development in Africa (Volume 10, No.4, 2009)

ISSN: 1520-5509

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Impacts of a Solid Waste Disposal Site on Soil, Surface Water and Groundwater Quality in Dar es Salaam City, Tanzania

By

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ABSTRACT

Solid waste disposal sites are potentially serious sources of pollution to the environment, especially when located very close to water sources and operated haphazardly. The high pollution potential of these sites is due to the fact that they usually contain almost all types of pollutants from the source community. The contaminants can leach out through the soil, contaminating the soil itself, ground water, and surface water. In the study reported here, environmental pollution impacts of a solid waste disposal site were investigated. Wet and dry seasons samples of soil, river sediments, groundwater, and surface water from sites suspected to be affected by the dumpsite were analysed for chemical, physical, and bacteriological parameters, including heavy metals such as Pb, Cd, Cr, and Zn, and nutrients (N and P). The dumpsite was found to be a significant ($p<0.05$) source of pollution to soil, groundwater, surface water and riverbed sediments in its neighbourhood. Concentrations of, among others, Pb and Cd in groundwater were as high as 15 and 35 mg/L, respectively. Seasons were also found to be an important factor in the occurrence and magnitude of pollution, and pollution was found to occur mostly through migration of leachate. This reasserts the notion that proper design, construction, and operation of dumpsites to reduce infiltration of rainwater and contain leachate can curtail pollution considerably.

Keywords: Solid waste disposal site; Water quality; Groundwater; River sediments; Soil pollution; Tanzania

1.0 INTRODUCTION

Solid waste management has been laden with the most serious environmental sanitation problems in urban areas in Tanzania during the past two decades. The problems have manifested in the form of piles of uncollected waste, discharge of wastes at unauthorised sites, and unsanitary operation of disposal sites. The problems came to a head in the middle and late 1990s when only between 5 and 10% of urban areas in Tanzania were being provided with solid waste management services (Mato et al., 1997). The most apparently serious solid waste management problems were observed in Dar es Salaam City, the *de facto* capital city of Tanzania. The problems prompted a political interference followed by drastic remedial measures. The remedial measures included the overhauling of the City administration, which was considered an impediment to initiatives designed to improve the status of the city. The most important direct measure with respect to solid waste management was privatisation of the service. This measure increased the coverage apart from improving the delivery of the service. As a direct result of these improvements, piles of uncollected wastes and incidences of illegal disposal of wastes decreased, which in turn led to an increase in the amounts of waste collected. However, the increase in amounts of waste collected aggravated an existing problem of waste disposal. As a result, the most serious solid waste management problem in Dar es Salaam city is disposal, a fact which is still true to day (Kaseva and Mbuligwe, 1999; Kassenga et al, 2002).

The Vingunguti solid waste disposal site is located to the west of the City. The dumpsite is located right adjacent to Msimbazi River, which flows through the City. The capacity of Vingunguti disposal site is already exhausted. The site is not capable of accommodating even a fraction of the waste generated by city, which is estimated to be more than 1900 tons/day (Kassenga and Mbuligwe, 2004). As a result, the disposal site exhibits highly unsanitary conditions, which prompted a court wrangle between City authorities and communities in the neighbourhood of the site. Additionally, the site has been alleged to be a source of pollution to the environment. Notably, the use of the Vingunguti site for disposal of waste from the city began after eviction from another site, known as Tabata in 1992. The irony of the situation is that, the eviction was prompted by precisely the reasons observed in respect of the Vingunguti site. Residents near the Tabata site took the city authority to court and won a high court case that resulted in the eviction.

The shifting of the disposal site to Vingunguti was recognised to be environmentally delicate, but at the time the decision was made some residents adjacent to the site invited the city authority to locate the disposal site near their houses. They wanted the dumpsite to be located near their houses because it would give them an opportunity to use the waste to protect their pieces of land, which were being threatened by erosion, which was in turn caused by flooding of Msimbazi River. With time, the problem of erosion was superseded and eventually outweighed by nuisance and potential pollution from the dumpsite. Apart from causing protests from residents in the vicinity of dumpsite, the situation of the dumpsite has prompted the need for an assessment of the impacts of the dumpsite on the environment. This paper outlines findings from a study on effects of the disposal site on Msimbazi river water, groundwater, soil, and river sediments. The study covered both the wet and dry seasons in order to capture the influence of seasons on the impacts of the dumpsite.

2.0 DESCRIPTION OF THE STUDY AREA

Msimbazi River originates in Kisarawe highlands in Coast region, to the south - west of Dar es Salaam city. It flows between latitudes 6^{o} 4’ 2.5’’ and 6^{o} 5’ 3.4’’ S towards the north - east direction, and enters the Indian Ocean on the northern part of Dar es Salaam City. As it flows into the sea, it is joined by many tributaries and man-made drains that serve some parts of the city. It covers a distance of about 46 km (Rwenyagira, 1988). The lower reaches of the river, including the section that flows adjacent to Vingunguti dumpsite, are perennial. The river has wide flood plains, which are as wide as 1100m in some areas and cover around 41 km^2. The coverage of the flood plains amounts to about 15% of the total Dar es Salaam City area (Rwenyagira, 1988).

Like the rest of Dar es Salaam city, rainfall in the Msimbazi River catchment comes in two seasons: March – June and October – December, and the annual rainfall ranges between 1000 and 1200mm. Discharge data for Msimbazi River are hard to come by but measurements carried out by Rwenyagira (1988) give a range of 0.215 and $0.448m^3/s$.

Msimbazi valley serves a lot of ecological, socio-economic, utility, and agricultural purposes to residents of Dar es Salaam, a city with a 2001 estimated population of between 3 and 4 million. It has ecological value as a green belt, especially due to its wetlands as well as its close tie with the Indian Ocean. The wetlands attenuate pollution from industrial outfall sewers and residential on-site sanitation systems. They additionally serve as habitats for flora and fauna and provide feeding areas for fauna. The valley also provides farming areas for urban agriculture, which thrives in the city. Parts of the valley accommodate playgrounds and gathering places for religious congregations and political meetings. Additionally, the valley serves as a one of the major primary drainage courses for the city, a role which helps to attenuate floods. The river itself provides a source of fish, especially in the upstream stretches. It is also used for bathing and washing, especially during periods of water shortages. Additionally, water from the river is used for irrigation in farms located along the river during the dry season.

Vingunguti dumpsite is located on a sloping piece of land adjacent to Msimbazi River, and was formed out of a small depression which is now full of solid waste. To get more space for dumping waste, the section of Msimbazi River adjacent to the dumpsite was straightened. To increase the capacity of the dumpsite and keep the dumped waste in place, a stone masonry retaining wall was constructed between the dumpsite and Msimbazi River. However, to release pore pressure, the retaining wall was provided with weepholes, through which leachate can escape from the dumpsite directly into Msimbazi river.

Initially, there were intentions to operate the dumpsite in a somewhat sanitary manner. Bulldozers were used to compact and partly cover the waste. The compaction was done to reduce the volume of the waste and increase the lifetime of the dumpsite as well as keep scavengers at bay. However, these measures were only short-lived. Before long, equipment for compacting and covering the waste fell into disrepair. This problem was in addition to equipment going without fuel every now and then. As a result, the situation at the site got worse and worse. Eventually, the dumpsite ended up being operated haphazardly with attendant public health and environmental implications.

3.0 MATERIALS AND METHODS

3.1 Sampling points for water and soil and timing of sampling

3.1.1 Surface water samples

Sampling points for surface water were along Msimbazi River, which runs adjacent to the dumpsite. The sampling points were strategically located to quantify the impact of the dumpsite on river's water quality. The descriptions and basis for the selection of the sampling points identified as RS1, RS2, RS3, RS4 and RS5, and LS are as follows.

RS1 was located upstream of the dumpsite, and its location was meant to give the baseline water quality conditions in the river. RS2 was located immediately downstream of the dumpsite and its location was meant to represent water quality conditions after leachate from the dumpsite has mixed with river water. RS3 was located (at Nelson Mandela Road crossing) at a distance of about 1.6 km downstream of RS2. It was selected to gauge the extent of attenuation of pollution discharged from the dumpsite. RS4 was located at a distance of about 3.5 km downstream of RS3. The basis for its location is similar to that for RS3. RS5 was located at a distance of about 1.65 km downstream of the dumpsite. RS5 was located where appreciable tidal effects from the Indian Ocean could be observed. The location of RS5 was also meant to serve the purposes described in respect of RS3 and RS4. LS was the sampling point for leachate coming out through a weephole of a retention wall of the dumpsite. LS samples were meant to depict the characteristics of leachate from the dumpsite, which could pollute soil, surface water, and groundwater.

Grab samples were collected on the same day every week simultaneously at all sampling points, and where necessary they were analysed on the same day. Sampling was done 12 times on weekly basis during a period that spanned over both dry and rainy seasons.

3.1.2 Groundwater samples

Samples for groundwater were taken from points identified as CWS and UWS. CWS (for contaminated groundwater sample) was a well located about 10m downstream of the dumpsite. The well was suspected to be contaminated with leachate from the dumpsite on account of is spatial and hydrologic characteristics such as proximity to the dumpsite, groundwater flow direction and topography. UWS (for uncontaminated groundwater sample) was a well about 10m upstream of the dumpsite. This well was not suspected to be contaminated by leachate from the dumpsite due to its upstream location with respect to hydrologic and spatial influences. Sampling for groundwater was done in the same way as for surface water.

3.1.3 Soil samples

Soil samples were taken from four locations in close proximity of the dumpsite at locations identified as UGS, DGS, URS and DRS. UGS (for upstream ground soil sample) was located upstream of the dumpsite (in relation to groundwater flow). UGS was meant to depict the baseline conditions. DGS (for downstream soil sample) was located downstream of the dumpsite (in relation to groundwater flow). DGS was intended to portray effects of contamination from the dumpsite. Wet samples of soil were taken below the ground water table at both sampling points by using an auger.

River sediment samples were taken from the bed of Msimbazi River. URS (for upstream river sediment sample) was located upstream of the dumpsite to portray baseline conditions. DRS (for downstream river sediment sample) was located downstream of the dumpsite to depict effects of pollution from the dumpsite. Sediment samples were collected from the bed of the river by scooping, minimising wash out of the sediments.

3.2 In-situ analytical instruments and measurements

In-situ measurements were done for dissolved oxygen (DO), pH and electrical conductivity (EC), using portable DO, pH and EC meters, respectively. The measurements were done by dipping the DO, pH and EC meter probes into freshly collected water samples from different points and depths across the river section. Mean readings observed were taken to be representative of each sampling location. In-situ measurements were done simultaneously with sampling.

3.3 Analytical methods

3.3.1 Water samples

Water samples were analysed for manganese (Mn), iron (Fe), suspended solids (SS), faecal coliform (FC), turbidity, colour, chloride (Cl); and sulphate (SO_4^{-2}). Also analysed were cyanide (CN), and heavy metals (lead (Pb), cadmium (Cd), Chromium VI (Cr^{6+}) and total chromium (Cr)). Total nitrogen (T-N), Total phosphorus (T-P), BOD_5, and COD were also measured. Analysis for FC, BOD_5, T-N and T-P were carried out within an hour after sample collection to avoid sample deterioration. Analysis of surface and groundwater for the above listed parameters was done in accordance with standard methods for the analysis of water and wastewater (APHA, 1992).

3.3.2 Soil samples

Before analysis, soil samples were treated to prepare them for the subsequent analyses. All the soil samples were first air dried overnight in an oven at 32^{o}C. The dried samples were then mechanically ground and sieved through 200mesh size sieve. Five grams of each sieved sample was placed in an Erlenmeyer flask. Twenty millilitre of extracting solution (0.05N HCl + 0.025H_2SO_4) was added and the sample placed in a mechanical shaker for 15 minutes. The resulting solution was filtered through a Whatmann # 42 filter paper into a 50 ml volumetric flask and diluted to 50ml with the extraction solution.

The treated samples were analysed for different metallic ions using an Atomic Absorption Spectrophotometer (AAS) (Perkin – Elmer, Model 2380). The AAS settings were as shown in Table 1.

Table 1: Settings for the AAS for the Analysis of Metal Ions

Metal ion	Wavelength (nm)	Slit width (nm)
Cr	357.9	0.7
Pb	283.3	0.7
Cd	228.8	0.7
Mn	279.5	0.2
Fe	248.3	0.2
Zn	213.9	0.7
Cu	324.7	0.7
CN	578.0	0.7

3.4 Statistical Analysis

Statistical analysis was done to establish the statistical significance of the dumpsite as the main source of pollution to soil, surface water and groundwater near the dumpsite. Paired t-tests were performed as the basis for judging the significance of the analytical results and in-situ measurements. The results were considered statistically significant if $p < 0.05$.

4.0 RESULTS AND DISCUSSION

4.1 Impacts of the dumpsite on surface water quality

Table 2 presents results of analysis of water quality along Msimbazi River upstream and downstream of the dumpsite for selected parameters. It also presents results of analysis of leachate (LS) from the dumpsite and ground water from two sampling wells upstream of the dumpsite (UWS) and downstream of the dumpsite (CWS).

Table 2: Comparison of Water Quality along Msimbazi River and in Wells Downstream and Upstream of Vingunguti Dumpsite between Wet and Dry Seasons (based on means of measured values for various parameters)

Sampling points		Points along Msimbazi River					Selected points		
Parameter	Period	RS1	RS2	RS3	RS4	RS5	LS	CWS	UWS
Mn (mg/L)	Wet	0.00	0.00	0.00	0.00	0.00	0.11	0.05	0.00
	Dry	0.00	0.01	0.00	0.00	0.00	0.04	0.02	0.03
Fe (mg/L)	Wet	1.39	0.99	0.79	0.70	0.68	15.0	0.24	0.12
	Dry	0.87	0.64	0.71	0.66	0.70	13.78	0.12	0.07
SS (mg/L)	Wet	77.	131	59	88	86	1242	67	24
	Dry	28	38	30	32	50	464	33	12
FC (counts × 10^4 /100mL)	Wet	3	5	58	2.7	5.7	17.7	3.7	0.70
	Dry	3.69	3.89	5.11	5.82	11.7	1.96	3.42	1.5
Turbidity (ntu)	Wet	65	70	65	45	62	828	28	6.5
	Dry	30	41	35	36	33	702	20	3.1
Colour	Wet	214	316	295	258	248	3377	73	54
	Dry	207	194	247	224	215	5813	70	28
Cl (mg/L)	Wet	402	413	408	410	397	5580	140	141
	Dry	434	450	442	372	354	4348	159	130
EC (mS/cm)	Wet	8.7	9.4	9.5	9.0	9.7	105	5.3	5.0
	Dry	8.9	9.8	10.3	10.4	11.2	150.6	6.5	5.4
SO_4^{-2} (mg/L)	Wet	56	34	60.4	25	32	133	72	35
	Dry	79	61	67	456	60	146	49	76

RS1 = sampling point along Msimbazi River upstream of the Dumpsite
RS2 = sampling point along Msimbazi River immediately downstream of the Dumpsite
RS3 = sampling point along Msimbazi River downstream of RS2 (Nelson Mandela road crossing)
RS4 = sampling point along Msimbazi River downstream of the RS3 (Kigogo road crossing)
RS5 = sampling point along Msimbazi River downstream of the RS4 (Morogoro road crossing)
LS = sampling point for leachate from a weep hole at the base midway along the dumpsite
CWS = well close of the dumpsite which is suspected to be contaminated due to spatial characteristics (proximity, groundwater flow direction, topography)
UWS = well upstream of the dumpsite not suspected to be contaminated) with leachate due to spatial characteristics (proximity, groundwater flow direction, topography)

Table 2 shows that the concentrations of various contaminants in the leachate from the dumpsite is significantly higher than those reported in literature (for example, Tchobanoglous et al., 1993). For all parameters except FC during the dry season the concentrations in leachate are as high as one order of magnitude more than in river water as well as ground water. Concentrations of Mn in river water during both the wet and dry seasons were below detection limit despite being detected in leachate and groundwater. The high strength of leachate signifies its higher pollution potential.

It is clear from Table 2 that, the seasons affect the concentrations of pollutants in water in the river as well as in the leachate from the dumpsite. For most parameters, the wet season produced higher concentrations of pollutants. The influence of seasons stem from the fact that rainwater dilute pollutants in the river apart from the fact that storm water runoff washes pollutants into the river.

Table 1 further shows that, for SS, Cl^-, EC and turbidity for both the wet and dry seasons concentrations show a fairly sharp increase at the dumpsite followed by a comparably sharp decrease immediately after the dumpsite. Thereafter, a gradual decrease is observed. This suggests that the increase in pollution is caused by pollutants originating from the dumpsite. The sharp decrease in concentrations downstream of the dumpsite is likely to be caused by dilution of the pollutants as the leachate mixes with water in Msimbazi River. The gradual decrease in concentrations of the pollutants further downstream of the dumpsite is likely to be a result of the natural purification processes in the river.

The pattern observed in respect of SS, Cl^-, EC and turbidity applies to colour but only for the wet season. This is likely to be because infiltration of rainwater facilitates the dissolution of colour producing substances in the dumpsite. It can also be observed that colour levels are fairly uniform along the river during the dry season. This uniformity of colour level suggests that, there is no natural purification in the river in respect of colour. Alternately, more colour producing contaminants are added from external sources all along the river, as a result of which the additions compensate for any decrease resulting from degradation. The decrease in colour observed in the wet season could be due to dilution by runoff that enters the river all along its length.

Concentrations of suspended solids and turbidity are higher in the wet season than the dry season, which is likely to be due to the fact that the pertinent contaminants are washed into the river by runoff. The pattern depicted by concentrations of iron (Fe) along the river does not render itself to a simple explanation in connection with the dumpsite. It is likely that, sources of Fe are spread out all along the river. However, the dumpsite is a significant source of Fe, judging on the basis of the concentration of Fe in the leachate as compared to water from the wells during both the dry and wet seasons.

The pattern shown by concentrations of sulphate is not clear enough for an explanation that relates to the dumpsite as a source of pollution. The observed higher concentrations of sulphate during the dry season than the wet season can be attributed to the fact that, due to low river flow during the dry season dilution is reduced. Near settlements that use on-site sanitation systems, ground water table is elevated and ground water flow is sustained by water infiltrating from the sanitation facilities. This ground water can carry pollutants into the river when runoff has ceased and river water flow has decreased considerably.

The pattern exhibited by FC counts in the river can be explained by the fact that, Msimbazi river valley is flanked by settlements all along its length. Majority of residents in theses settlements use on-site sanitation systems like pit latrines, which can act as sources of bacteriological pollution, especially when they overflow. As such, the pollution profile along the river can be distorted. The increase in FC counts in the dry season can be explained by the fact that, due to low river flow during the dry season dilution is reduced. Apparently, dilution is the main factor in the reduction of the FC counts in the river. On the whole, the impact of the dumpsite on both the river and groundwater is statistically significant ($p < 0.02$).

Figures 1 through 6 present the profiles of mean (n = 12) concentration levels of TP and TN, Cr(all) and Cr^{6+}, Pb and Cd, CN, BOD_5 and COD, and DO and Turbidity along the river slightly upstream and downstream of the dumpsite. These are also meant to portray the influence of the dumpsite on water quality in the river during both the wet and dry seasons, and as such reinforce the findings depicted in Table 2.

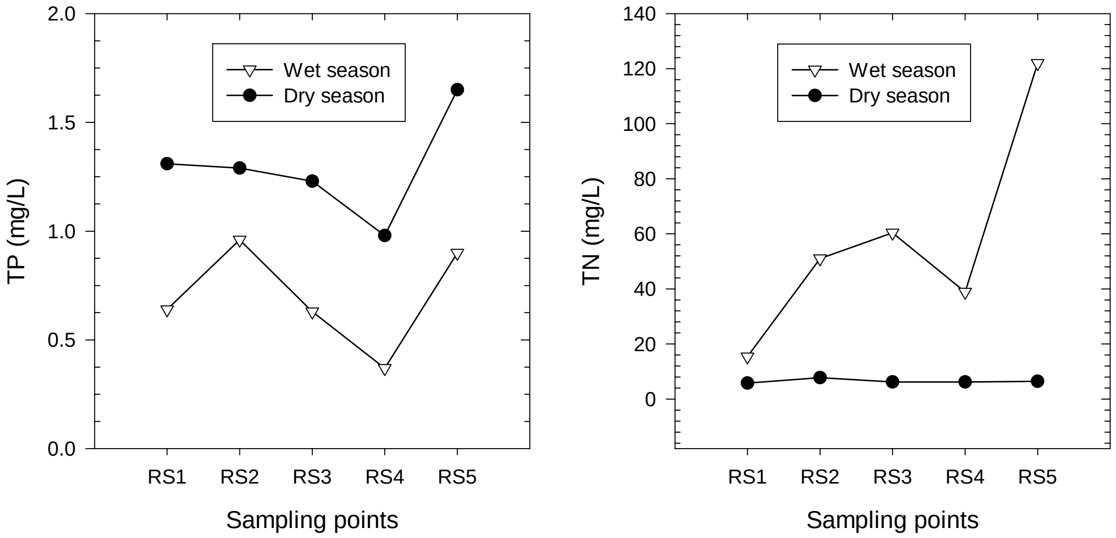

Figure 1: Variation of Total Phosphorus (TP) and Total Nitrogen (TN) Concentrations along Msimbazi River during the Wet and Dry Seasons

It is apparent from Figure 1 that the patterns of TP and TN are slightly different during the dry season. However, there is a discernible similarity with respect to the high level at RS2, the dipping at RS4, followed by the rise at RS5 during the wet season. The profile of TN suggests a remarkable influence from the dumpsite during the wet season. Overall, the profiles of TN and TP suggest clearly that the dumpsite might not be the sole cause of pollution. Notably, along Msimbazi river valley there are farms on which fertilisers, which contain both nitrogen and phosphorus, are applied. It can be presumed that the residues of fertilisers from the farms are washed into the river during the rain season. Additionally, on-site sanitation systems in the settlements that are adjacent to the river valley may be another source of TN and TP via both surface runoff and infiltration. Surface runoff occurs during the rain season only while infiltration occurs both during the wet and dry seasons. Use of phosphorus-based detergents contributes more TP in the effluents from the on-site sanitation systems. The additional phosphorus quantity from the detergents could be responsible for the observed high TP values during the dry season.

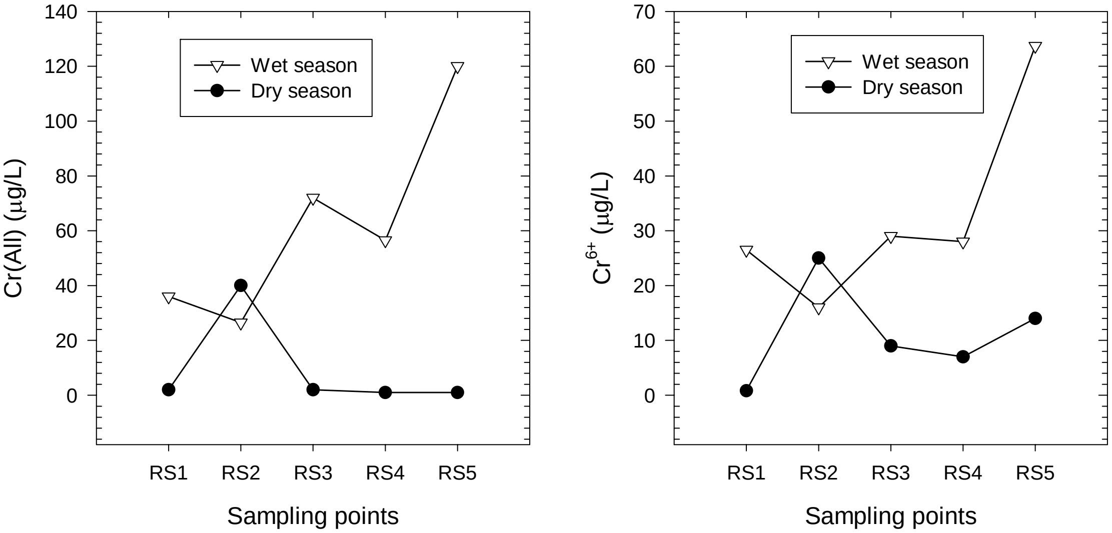

Figure 2: Variation of Total Chromium Cr(all) and Chromium VI (Cr^{6+}) Concentrations along Msimbazi River during the Wet and Dry Seasons

Figure 2 shows that the profiles of Cr(all) and Cr^{6+} were similar during both the wet and dry seasons. Also, the profiles suggest a discernible influence from the dumpsite, which is manifested by the sharp rise in concentrations of both species at RS2, followed by a relatively uniform concentration profile further downstream during the dry season. During the wet season, there was a sharp dip at RS2 for concentrations of both species. The profiles for the rest of the points downstream were the same for both species suggesting that they were influenced by the same phenomena. It is possible that more chromium is washed into the river by runoff during the rainy season. The increase in concentrations in the downstream direction can be explained by the fact that the catchment of pollutant sources increases with the distance downstream of the river. It appears as if, the concentration of chromium during the dry season is not influenced by the sources spread out along the river as much as by the dumpsite.

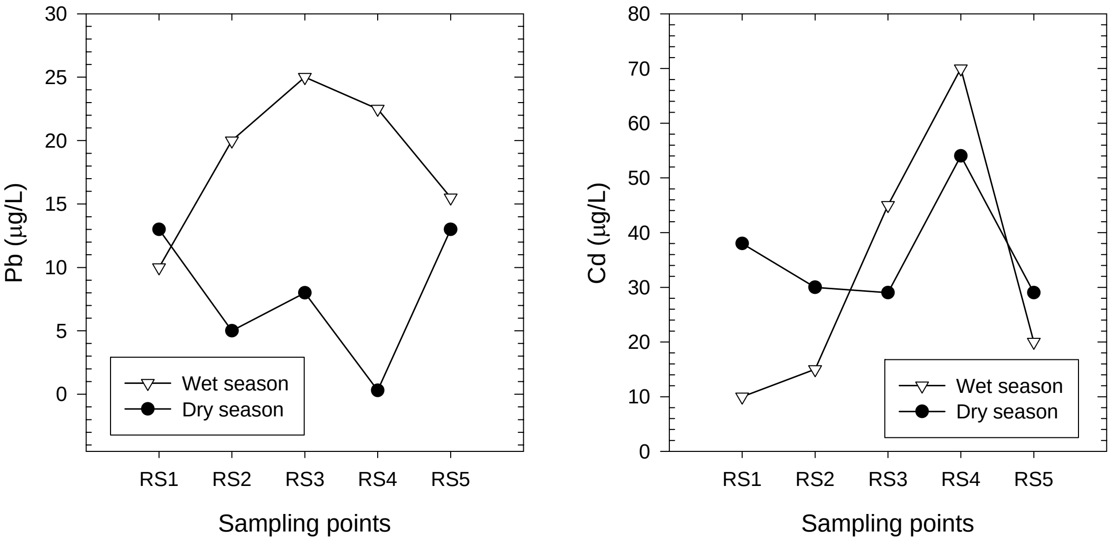

Figure 3: Variation of Lead (Pb) and Cadmium (Cd) Concentrations along Msimbazi River during the Wet and Dry Seasons

Concentrations of Pb in Figure 3 show a somewhat inverse relationship between the seasons, which cannot be explained easily. The wet season depicts generally higher concentration levels, which suggest that surface runoff contributes significantly to the observed pollution. An additional observation is the lack of any discernible signs of influences of the dumpsite on the river water quality changes.

The profiles of Cd concentrations for both the wet and dry seasons suggest the presence of a significant source of pollution in the neighbourhood of RS4. This could be one of industrial wastewater outfalls that discharge downstream of the dumpsite, especially between RS3 and RS4. The profiles of the concentrations of Cd during the two seasons depicted in Figure 3 cannot be explained adequately based on the knowledge of site conditions alone. It is however apparent that the influence of the dumpsite with respect to Cd concentrations in the river water is not clear-cut.

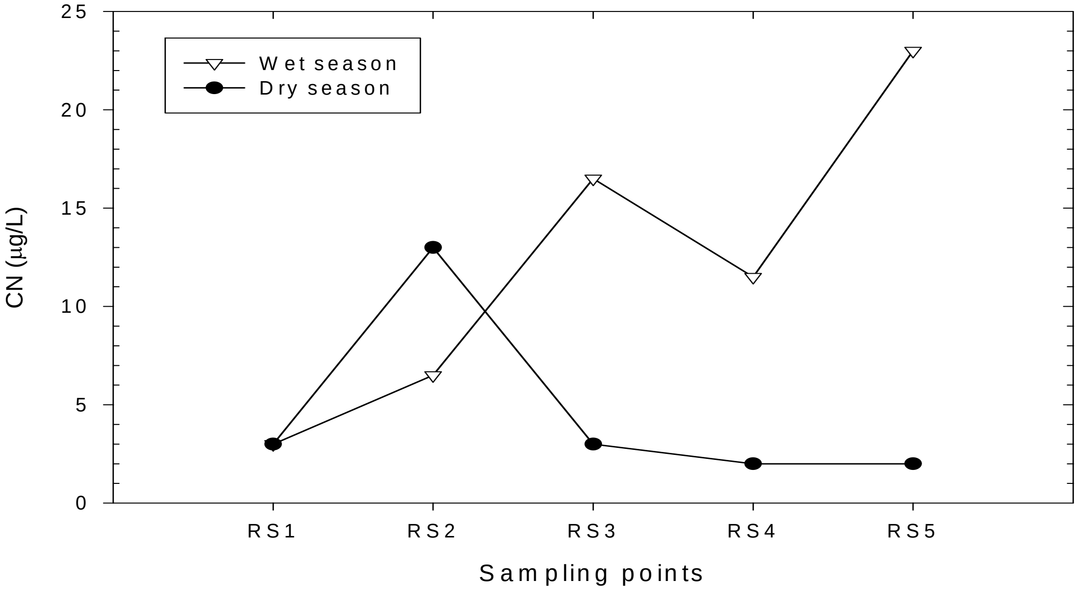

Figure 4: Variation of Cyanide (CN) Concentrations along Msimbazi River during the Wet and Dry Seasons

Figure 4 indicates the influence of the presence of the dumpsite on the water quality in the river during the dry season. This is attested by the rise and fall of CN concentrations across RS1, RS2 and RS3. It is apparent that, during the rainy season rainwater distorts the pattern of CN concentrations through dilution and washing into the river CN from diffuse sources in Msimbazi river valley. The fact that the concentration of CN increases in the direction of the river flow attests to this fact. The increase in pollution in the downstream direction can be explained by the fact that, the catchment of the river (which is also the catchment of pollution sources) increases with distance of the river. The non-uniformity of the concentration profiles of CN depicted in Figure 4 is most probably due to the fact that non-point sources of pollution do not necessarily release pollutants at the same rate. Also, possible simultaneous effects of degradation, dilution, and dispersion down-gradient of the river may contribute to the distortion of the profiles.

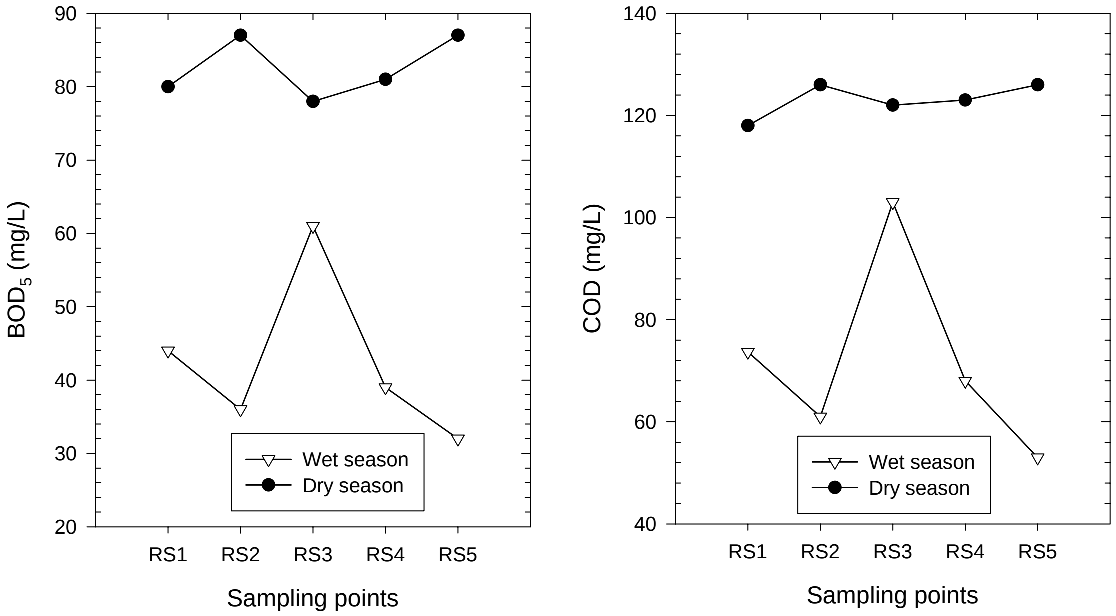

Figure 5: Variation of BOD_5 and COD Concentrations along Msimbazi River during the Wet and Dry Seasons

In Figure 5 it can be noted that concentrations of both BOD_5 and COD were highest during the dry season. There is also a clear indication that the dumpsite had an influence on the profiles of dry season BOD_5 and COD concentrations. The slightly higher level of concentrations at RS2 relative to upstream and downstream levels attests to this assertion. It is apparent that during the wet season, the concentration rises sharply at RS3, which is downstream of the dumpsite. This rise could be because of pollutants washed into the river by surface runoff. The observed lower concentrations of both BOD_5 and COD during the wet season is likely to be due to dilution caused by rain water.

Another notable observation with respect to Figure 5 is that, the concentrations of BOD_5 and COD in the water are in the ratio of around 1 to 1.5. According to Crites and Tchobanoglous (1998), this ratio signifies constituents that are not easily biodegradable. Such water constituents would not exert any apparent BOD on the water. This observation helps to explain why the corresponding DO concentrations as shown in Figure 6 are high.

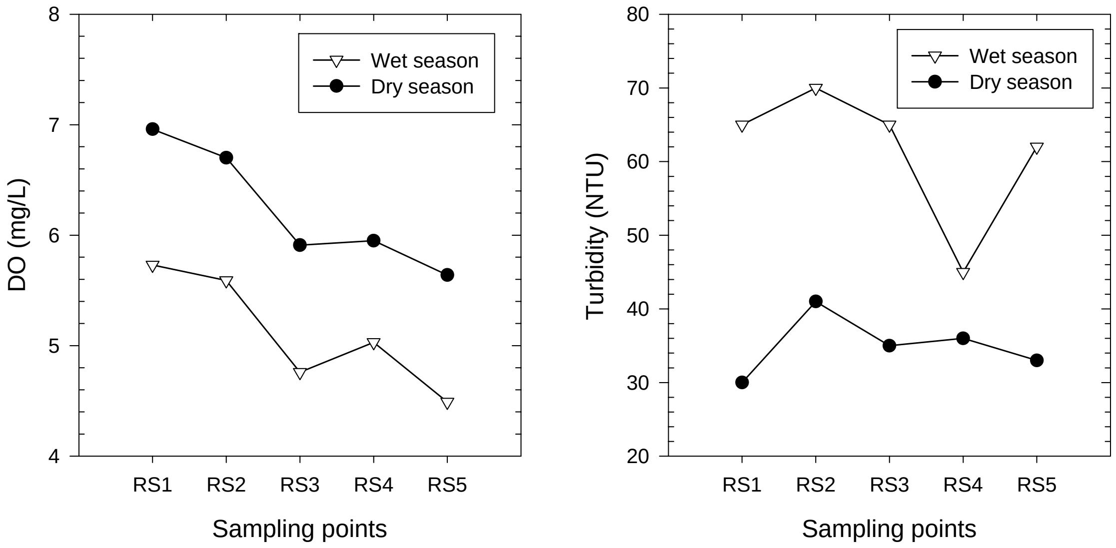

Figure 6: Variation of Dissolved Oxygen (DO) Concentrations and Turbidity along Msimbazi River during the Wet and Dry Seasons

Figure 6 shows that the DO concentrations are higher during the dry than during the wet seasons, with a difference of around 1mg/L between the seasons. The lowest DO concentration during the wet season is around 4.5mg/L, which is just above the minimum suitable concentration for most fish specie and other aquatic life forms (Milhelcic, 1999). On the basis of DO concentration alone, it can be said that, fish can survive well in the river. However, this much low a concentration is a borderline case, and as such it is not desirable since it does not leave much room for a fish survival, should there be a discharge of pollutants whose concentrations are exceptionally high.

As expected, Figure 6 shows that during the wet season the turbidity levels are higher than during the dry season. The high turbidity during the wet season can be explained by the fact that, rains bring in solid materials that are responsible for increasing turbidity in the water. Rains also cause re-suspension of settled materials, with possible increases in turbidity.

It is worth noting that, in addition to the parameters discussed above, analyses for chlorinated hydrocarbons such as tetrachloroethylene, trichloroethylene, and 1,1,1 trichloroethane on water samples were done. However, the pollutants were not detected in the samples.

4.2 Impacts of the dumpsite on ground water quality

Table 3 compares groundwater quality between sources downstream and upstream of the dumpsite during wet and dry seasons during the study. It also depicts the quality of leachate from the dumpsite during the same period. Table 3 further serves to show how leachate from the dumpsite influenced the quality of groundwater in its vicinity.

Table 3: Comparison of Groundwater Quality between Downstream and Upstream of Vingunguti Dumpsite for Wet and Dry Seasons for Heavy Metals and other Selected Parameters (based on mean values)

		Sampling Points		
Parameters	Seasons	Leachate (LS)	Downstream (CWS)	Upstream (UWS)
CN (µg/L)	Wet	79.5	11.0	5.5
	Dry	11.0	2.0	1.0
Pb (µg/L)	Wet	60.0	15.0	5.0
	Dry	160.0	21.0	0.00
Cd (µg/L)	Wet	73.0	35.0	10.0
	Dry	16.0	5.0	3.0
Cr^{6+} (µg/L)	Wet	115.0	18.0	5.5
	Dry	33.0	0.8	0.3
Cr (all) (µg/L)	Wet	245	31.5	11
	Dry	20.0	5.0	0.0
T-P (mg/L)	Wet	14.5	0.74	0.58
	Dry	22.2	1.46	0.70
T-N (mg/L)	Wet	522.1	291	23.6
	Dry	600.9	5.2	42.7
BOD_5 (mg/L)	Wet	1104	41	41
	Dry	1051	45	22
COD (mg/L)	Wet	1390	57	59
	Dry	1577	70	34
DO (mg/L)	Wet	0.41	4.32	4.23
	Dry	0.13	5.6	5.8

LS = leachate from the dumpsite taken through a weephole at middle of the dumpsite
CWS = groundwater from a sampling well downstream of the dumpsite
UWS = groundwater from a sampling point upstream of the dumpsite

The comparison of concentrations of various contaminants among leachate, and upstream and downstream wells shown in Tables 2 and 3, shows clearly that leachate from the dumpsite is a significant source of the pollutants. For each parameter, concentrations are highest in the leachate from the dumpsite followed by the sampling well downstream of the dumpsite. The sampling well upstream of the dumpsites has a consistently lower concentration for each contaminant except T-N. Overall, the influence of leachate from the dumpsite on groundwater and river water quality is statistically significant ($p<0.02$).

4.3 Impacts of the dumpsite on soil and river sediments quality

Table 4 presents data for results of analysis of soil and soil sediment samples from various points upstream and downstream of the dumpsite along Msimbazi River and in the ground upstream and downstream of the dumpsite.

Table 4: Soil Contamination for Samples of Msimbazi River Sediments and Soil Upstream and Downstream of Vingunguti Dumpsite

		Sampling points			
Parameter	Units	UGS	DGS	URS	DRS
Cadmium (Cd)	mg/kg	0.143	0.176	0.143	0.256
Lead (Pb)	mg/kg	1.410	1.594	2.250	2.952
All chromium (Cr)	mg/kg	0.002	0.060	0.150	0.384
Chromium ($Cr6^+$)	mg/kg	0.001	0.040	0.080	0.200
Cyanide (CN)	mg/kg	2.181	0.423	0.732	0.312
Zinc (Zn)	mg/kg	1.721	2.289	1.721	5.819
Iron (Fe)	mg/kg	96.04	114.24	143.68	288.71
Manganese (Mn)	mg/kg	15.03	56.91	45.83	72.73

UGS = soil sampling pit dug in the ground upstream of the dumpsite
DGS = soil sampling pit dug in the ground downstream of the dumpsite
URS = sediment sampling point on the bed of Msimbazi River upstream of the dumpsite
URS = sediment sampling point on the bed of Msimbazi River downstream of the dumpsite

From Table 4, it is apparent that, the dumpsite has a significant influence on concentrations of Cd, Pb, Cr(all), Cr^{6+}, Zn, Fe, and Mn in both ground soil and river sediments. The computed statistical significance of the impact of the dumpsite on soil and river sediment is higher than 95% confidence level. These results correlate with those pertaining to the data for river water and groundwater quality. It can further be deduced that, some of the pollutants from the dumpsite that find their way into the river get deposited on the bed of the river. This can partly explain the unclear patterns of profiles of some of the pollutants depicted in Figures 1 through 6.

An examination of data on pollution of ground water and soil as well as sediments as presented in Tables 2 and 4, suggests strongly that pollution of both surface and groundwater by the dumpsite takes place mainly through migration of leachate. This implies that, surface runoff plays a much less significant role, if any.

5.0 CONCLUSION AND RECOMMENDATIONS

Vingunguti solid waste disposal site is located very close to a surface water body, Msimbazi River. The river is used as a source of fish as well as water for potable uses, washing, and irrigation for some of Dar es Salaam City residents. The dumpsite was neither properly designed and constructed to contain leachate nor is it operated in a way that keeps out rainwater, which is responsible for the formation of leachate. As a result, it causes pollution of river water, groundwater, soil, and river sediments. Concentrations of heavy metals Pb and Cd in groundwater, for example are as high as 15 and 35mg/L, respectively. Since water from the river is used for domestic purposes as well as for irrigation of vegetable crops, and fish from the river are eaten, the dumpsite presents a potential source of serious health hazards. The paper has revealed that, leachate is the main pathway for pollution of river water, groundwater, soil, and river sediments. As such, the location of the dumpsite close to the river and its haphazard operation, and especially the fact that rainwater is allowed to flow through the waste, are important precursor conditions of the observed pollution.

Seasons have been found to influence the magnitude as well as the occurrence of pollution emanating from both the dumpsite and other sources. Rainwater flows through the waste in the dumpsite, which is not covered, leaching out pollutants, which in turn it transports away from the dumpsite. Additionally, surface runoff washes some pollutants from polluted ground surface into the river.

It is apparent that the pollution caused by Vingunguti dumpsite could have been avoided by a combination of some measures. One measure is good site selection, so as to keep the waste away from water sources. Another is good design and construction with a view to avoiding potential pollution problems through using landfill liners and providing for suitable cover materials. The final measure is good operation so as to keep out rainwater and contain as well as treat leachate whose formation cannot be prevented.

ACKNOWLEDGEMENTS

The study described in this paper was carried out under the auspices of the Department of Environmental Engineering (DEE), Ardhi University (ARU). It was funded by the Japan International Cooperation Agency (JICA). The authors wish to acknowledge the roles played by JICA and staff of DEE in the study.

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